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SEPARATION ARRANGEMENT

Background of the Invention

1. Field of the Invention

The present invention relates to a filter assembly, and more particularly, to a filter assembly including a filter element and a support cage. The present invention also relates to an end cap, and more particularly, to an extendable end cap or a slidable end cap which allows the filter element to move in the axial direction while maintaining a fluid tight seal.

2. Discussion of the Related Art

Separation devices are typically utilized to separate one or more components of a fluid from other components in the fluid. As used herein, the term "fluid" includes liquids, gases, and mixtures and combinations of liquids, gases and/or solids. A wide variety of common processes are carried out in separation devices, including, for example, classic or particle filtration, microfiltration, ultrafiltration, nanofiltration, reverse osmosis (hyperfiltration), dialysis, electrodialysis, prevaporation, water splitting, sieving, affinity separation, purification, affinity purification, affinity sorption, chromatography, gel filtration, bacteriological filtration, and coalescence. Typical separation devices may include dead end filters, cross-flow filters, dynamic filters, vibratory separation systems, disposable filters, regenerable filters including backwashable, blowback and solvent cleanable, and hybrid filters which comprise different aspects of the various above described devices.

Bag filters are currently utilized in a wide variety of fluid purification applications ranging, for example, from paint filtration to use in vacuum cleaners. Bag filters are typically formed from sheets of flexible material which are mounted in variously configured support structures. The sheets of flexible material may be sewn together to form a variety of configurations suitable for the particular filtration application.

In service, unfiltered fluid, e.g., a liquid, is directed through the bag filter wherein the filter medium sieves, blocks, contains, traps and/or otherwise removes contaminants from the unfiltered fluid to provide a filtrate containing substantially

fewer contaminants. Over time, the contaminants foul the filter medium, which in turn causes an increased pressure differential across the bag filter. When the pressure drop becomes substantial, indicating significantly reduced flow rates and/or constant flow with a reduction in downstream pressure, maintenance is required. Maintenance may take different forms. Most commonly, the bag filter is removed, discarded and replaced with a new bag filter.

Typically, bag filters have short useful lives because there is usually less available filtration surface area. Accordingly, bag filters may become fouled more quickly resulting in increased maintenance downtime and costs. In addition, frequent replacement of the bag filters may be prohibitively expensive.

In certain purification applications, for example, high fluid flow applications, filter assemblies comprising a single housing and multiple filter elements are utilized. The filter elements are usually smaller diameter filter elements which are typically pleated to increase filtration surface area. The filter elements are also usually limited in length because the machines utilized to form the filter medium into a pleated configuration corrugate across the shorter dimension of the filter medium. Smaller diameter, shorter length filter elements generally become fouled quickly given a process fluid having a high contaminant loading. Accordingly, filter assemblies comprising smaller diameter, shorter length filter elements typically have higher maintenance expenses and increased maintenance downtime necessitated by the high frequency of filter element changeout. In addition, a larger number of smaller diameter, shorter length filter elements are required to achieve the same or equivalent flow rates as fewer larger diameter, longer length filter elements, thereby contributing to increased maintenance expenses, e.g., the cost of filter elements, and system downtime, e.g., the time to change the filter elements.

The replacement of separation elements in a separation assembly may pose a time problem. For example, depending on the number of separation elements and the type of sealing arrangement utilized, the replacement of the separation elements may require a substantial period of time. The substantial period of time leads to an increase in expenses due to labor costs as well as assembly down time. In addition, a substantial period of time for replacements means a substantial period of time in which personnel may be exposed to potentially hazardous materials, for example

radioactive waste.

SUMMARY OF THE INVENTION

The separation assembly, separation element, and end cap of the present invention overcome the limitations of the prior art by providing a reliable and inexpensive separation element which offers increased surface area available for filtration. The separation assembly, separation element, and end cap may be utilized in a wide variety of filtration applications. In addition, the separation assembly, separation element, and end cap may be utilized in currently employed systems.

In accordance with one aspect, the present invention is directed to a separation element. The separation element comprises two or more hollow pack sections, joiner caps, and first and second end caps. Each hollow pack section has first and second ends and an interior and includes a porous medium which comprises a polymeric material or a glass fiber material. The joiner caps are attached to at least one end of each of the two or more pack sections and adjacent joiner caps are connected to coaxially secure the pack sections and joiner caps into a hollow separation arrangement which is at least about forty inches in length and has an interior diameter of at least about two inches. The first and second end caps are attached to the hollow separation arrangement. One of the first and second end caps comprises a seal which has an outside diameter greater than the largest outside diameter of the hollow separation arrangement.

In accordance with a further aspect, the present invention is directed to a separation element. The separation element comprises a hollow pleated pack which has an interior and no more than two end caps connected to ends of the pack. The hollow pleated pack includes a porous medium comprising a polymeric material or a glass fiber material and includes a plurality of axially extending circumferentially spaced side seals. The hollow pleated pack is at least forty inches in length and has an interior diameter of at least two inches.

In accordance with a further aspect, the present invention is directed to a

separation element. The separation element comprises a pack and an end cap. The pack includes a porous medium and a first end. The end cap includes a first segment mounted to the first end of the pack and a second segment spaced from the first end of the pack. The end cap is extendable from a first position in which the first and second segments are spaced a first distance from each other to a second position in which the first and second segments are spaced a second distance from each other. The second distance is greater than the first distance.

In accordance with a further aspect the present invention is directed to a separation element. The separation element comprises a pack which includes a porous medium and a first end, and an end cap having a first segment, a second segment mounted to the first end of the pack, and a sealing member coupled to at least one of the first and second segments. The first segment is slidably engaged to the second segment such that the first segment is movable between first and second positions. When in first position, the sealing member is relaxed, and in the second position, the sealing member is compressed by the first and second segments and thereby energized.

In accordance with another aspect, the present invention is directed to a separation assembly. The separation assembly comprises a support cage and a separation element. The separation element is removably mounted in the support cage and comprises a pack having an inner region and first and second ends which include a porous medium having pleats in a laid-over pleat configuration, a retainer arranged with the pack to maintain the pleats in the laid-over configuration, and first and second end caps which are connected to the first and second ends of the pack. The separation element is free of any support structure in the inner region of the pack.

In accordance with a further aspect, the present invention is directed to a separation assembly. The separation assembly comprises a support cage having a first end and a separation element removably mounted in the support cage. The separation element includes a pack and at least one end cap mounted to the pack. The at least one end cap is extendable to allow the separation element to move from a position removed from the first end of the support cage to a position in

proximity to or in contact with the first end of the support cage to reduce loading on the separation element.

In accordance with a further aspect, the present invention is directed to a separation assembly. The separation assembly comprises a support cage having a first end, a seat arrangement, and a separation element removably mounted in the support cage. The separation element includes a pack and at least one end cap mounted to the pack. The at least one end cap includes a seal arrangement which slidably engages the seat arrangement. The separation element is axially movable within the support cage from a first position. The seal arrangement engages the seat arrangement and the separation element is spaced from the first end of the support cage to a second position wherein the seal arrangement engages the seat arrangement of the separation element and is closer to the first end of the support cage.

In accordance with a further aspect, the present invention is directed to an end cap for capping an end of a separation pack. The end cap comprises a first segment including a first surface mountable to the end of the separation pack and a second segment including a sealing surface. The first and second segments are extendably connected such that the second segment is movable relative to the first segment.

For many embodiments, the filter assembly comprises a pleated filter element including one end cap which allows the filter element to move in the axial direction within a support cage. Specifically, the end cap allows the filter element to move from an initial position within the support cage to a final position in the support cage in which the filter element is in proximity to or in contact with the bottom end of the support cage, thereby reducing the tensile forces acting upon the filter element during filtration. The end cap also provides for a fluid tight seal around the pleated filter element to prevent fluid by-pass.

The exemplary filter assembly of the present invention provides for the effective and efficient filtration of a wide variety of fluids, i.e., both liquids and gases. Further, it provides for a less expensive, longer life filter element which may be utilized in any number of fluid filtering applications, including those applications wherein disposable and non-disposable bag filters and smaller diameter pleated

filters are currently utilized. The filter element typically has more surface area available for filtration than bag filters of equal or greater size. Accordingly, the filter element may be utilized for longer periods of time before fouling necessitates replacement, and thus maintenance time and maintenance costs are reduced. In addition, the exemplary filter element may be utilized in higher flow systems with minimal increases in volume.

The exemplary filter elements of the present invention may be utilized in a wide variety of filtration systems, including bag filter systems. For example, the filter element may be used in existing bag filtration system housings, thereby reducing potential capital expenditures in replacing the existing system. In addition, since the filter elements may comprise more surface area available for filtration because of the pleats and/or because longer filter elements are used, the flow of fluid through the system may be increased. One way in which to increase the flow of fluid through the system would be to decrease the volume of the filter containment vessel or housing. Decreasing the size of the housing typically results in a less expensive filtration system. Additionally, because of their pleating and size, the exemplary filter elements may be utilized in new filter vessels that are effectively smaller in diameter, thereby resulting in less floor space required, lower overall vessel cost, and less maintenance expense.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a sectional view of the filter with reusable cage of the present invention.

Figure 2 is a sectional view of an alternative embodiment of the filter of the present invention with a reusable cage.

Figure 3a is a top view of the second end cap of the filter of the present invention.

Figure 3b is a sectional view of the second end cap taken along section lines 3-3 in Figure 3a.

Figure 4a is a top view of the first end cap of the filter of the present invention.

Figure 4b is a sectional view of the first end cap taken along section line 4-4 in Figure 4a.

Figure 5 is a detailed illustration of a weld stake of a first section of the first end cap of the present invention.

Figure 6a is a top view of a third segment of the first end cap of the present invention.

Figure 6b is a sectional view of the third segment of the first end cap taken along lines 6-6 in Figure 6a.

Figure 7 is a cut-away perspective view of a filter element of the present invention.

Figure 8 is a transverse cross-sectional view of a portion of the filter element of Figure 8.

Figure 9 is an enlarged cross-sectional view of one of the pleats of Figure 9.

Figure 10 is a schematic perspective view of a portion of a filter composite.

Figures 11a and 11b are sectional views of an alternative embodiment of the filter of the present invention.

Figure 12 is a sectional view of an alternative embodiment of the pleated filter with reusable cage of the present invention.

Figure 13a and 13b are sectional views of an alternative embodiment of the filter assembly of the present invention.

Figure 14 is a top view of a filter pack having multiple side seals.

Figure 15 is a sectional view of a first embodiment of a filtration system housing.

Figure 16 is a sectional view of a second embodiment of a filtration system housing.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The exemplary filter assembly of the present invention may be utilized in a wide variety of separation applications, including the filtration of both liquid and gaseous materials. Accordingly, as stated above, the term fluid shall be understood to include both liquids and gases, as well as mixtures and combinations of liquids,

gases, and/or solids. Additionally, the filter assembly of the present invention may be utilized in various applications, including those designed for high volume filtration. The particular materials utilized for the specific elements comprising the filter assembly may vary in accordance with the particular fluid being filtered, for example, to maintain thermal or chemical compatibility.

In accordance with one aspect, the present invention is directed to an end cap or an end cap structure. For example, the present invention is directed to an end cap or an end cap structure which facilitates axial movement of a separation element such as a filter element.

One exemplary filter assembly of the present invention generally comprises a hollow, tubular filter element, including a filter pack and two end caps, and a perforated support basket or cage in which the filter element may be removably mounted. The filter pack may comprise a solid or hollow mass or a pleated structure any suitable medium or combination of media and is typically selected based upon the particular application for which it is to be utilized. The filter medium may have a uniform or graded pore structure. The filter pack as stated above may be non-pleated or pleated, and the pleats may extend radially or they may be in a laid-over configuration. The perforated support cage provides structural support for the filter element against outwardly directed forces caused by fluid flow during filtration. The perforated support cage may be removably mounted to a tubesheet or similar structure of a filter housing, or it may be permanently mounted thereto. One of the two end caps is preferably configured to allow the filter element to move in the axial direction while maintaining a fluid-tight seal with the tubesheet, which, for example, tends to reduce axially directed tensile forces acting upon the filter element. The axially directed forces acting upon the filter element are reduced because the forces are transferred to the perforated support cage when the filter element bottoms out in the perforated support cage. The perforated support cage is better able to withstand the axially directed forces and thus is not substantially effected by the forces. Reducing the forces acting upon the filter element decreases the likelihood of the filter element developing defects, and increases the useful life of the filter element. In addition, since the filter element may move axially within the perforated support cage while the one end cap maintains the fluid-tight seal, the

manufacturing tolerance on the filter element may be relaxed.

The exemplary filter may be mounted to a support structure, such as a tubesheet, and may be utilized to filter a wide variety of fluids ranging from nuclear materials to paints. For example, the exemplary filter assembly may be utilized to replace bag filters which are currently utilized in many of these applications, or for new filter vessel installations.

An exemplary filter assembly of the present invention may comprise a disposable filter element or a cleanable filter element. Cleanable filter elements include regenerable filter elements which may be cleaned by backwashing, blowback, and other similar processes, and filter elements which may be rinsed or soaked in various cleaning solutions. The exemplary filter assembly may also include, in addition to or alternatively to the support cage, an internal support structure such as a core which provides structural support for the filter element against inwardly directed forces caused by fluid flow during filtration or during any reverse flow occurrences. The filter element may comprise a wrap or a sleeve to provide additional support for the filter medium against the forces generated by fluid flow.

Figure 1 is a sectional view of an exemplary embodiment of a filter assembly of the present invention. As described above, the filter assembly 10 comprises a filter element 12 removably mounted in a perforated support cage 14. The filter element 12 includes a pleated filter pack 16 comprising at least one layer of a filter medium, a wrap 18, a first end cap 20, and a second end cap 22. The filter element 12 also comprises a handle 24 which facilitates the insertion and/or removal of the filter element 12 into or out of the perforated support cage 14.

The filter assembly 10 may be disposed in an opening in a tubesheet 26 of a filtration system, supported therein by the perforated support cage 14, and sealed to the tubesheet 26 by the first end cap 20. The tubesheet 26 may comprise more than one opening for more than one filter assembly 10. Typically, tubesheets comprise a plurality of openings to accommodate a plurality of filter assemblies. The filter assembly 10 may be vertically or horizontally oriented within the filtration system, or the filter assembly 10 may be oriented at any angle between vertical and horizontal. For example, the filtration system may include a housing having upper and lower sections with a tubesheet disposed therebetween. The filter assembly 10 may be

secured to the tubesheet and extend in the vertical direction into at least one of the upper and lower sections. Alternatively, the housing may have first and second sections oriented horizontally. Accordingly, the filter assembly 10 may be attached to the tubesheet in a horizontal orientation. A more detailed description of the attachment of the filters to the tubesheet is given subsequently.

The perforated support cage 14 axially supports the filter element 12 in the opening of the tubesheet 26. In addition, the perforated support cage 14 radially supports the filter element 12 against outwardly directed forces generated during filtration and also helps to give the filter element 12 axial strength and rigidity against bending. The perforated support cage 14 may be removably or permanently attached to the tubesheet 26. As stated previously, the filter assembly 10 of the present invention may be utilized to replace currently utilized bag filters; therefore, the flow of fluid during filtration will typically be from the inside to the outside of the filter element 12. However, if the flow of fluid during filtration were in the opposite direction or if a reverse flow were required, e.g., during a backwash or blowback, an inner support structure such as a support core may be utilized instead of, or in addition to, the perforated support cage 14 for additional stability and rigidity.

The perforated support cage 14 may comprise a substantially cylindrical configuration having first and second ends, preferably a first open end and a second end which is at least partially closed. The open end preferably comprises an increasing diameter tapered section 28 having an annular lip 30 or flange at an end thereof, while the remaining portion of the perforated support cage 14 has a substantially constant diameter. The annular lip 30 is supported by the tubesheet 26. For example, the annular lip 30 may rest upon a shoulder 32 along the outer periphery of the opening in the tubesheet 26 to support the perforated support cage 14 and the filter element 12. The tapered section 28 facilitates the insertion of the filter element 12 into the perforated support cage 14. Figure 4b provides an enlarged view of this portion of the filter element 12. In an alternative embodiment, the perforated support cage 14 may comprise a substantially cylindrical configuration with a slight taper along the entire axial length of the perforated support cage 14 for facilitating the insertion or removal of the filter element 12.

In an alternative embodiment, the open end of the perforated support cage 14 may comprise variously configured ends having a diameter which may vary depending upon the diameter of the opening in the tubesheet 26. This situation may arise when the filter assembly 10 is to be used in existing filter systems. In one instance, for example, the tubesheet 26 may have a larger opening than required for the filter assembly; accordingly, a larger diameter open end may be required.

The perforated support cage 14 may be configured such that there is a small gap 34 between an inner surface of the perforated support cage 14 and an outer surface of the filter element 12. This small gap 34 is preferably minimized to ensure that the perforated support cage 14 provides support for the filter element 12 while allowing space for manufacturing tolerances. This small gap 34 facilitates axial movement of the filter element 12 within the perforated support cage 14 during insertion of the filter element 12 and facilitates axial movement of the filter element 12 during filtration. The small gap 34 also facilitates the removal of the filter element 12 from the perforated support cage 14 without having to remove the perforated support cage 14 from the opening in the tubesheet 26, while providing and maintaining structural support for the filter element 12. The filter element 12 may be removed from the perforated support cage 14 even though the filter element 12 may have expanded during filtration. The gap 34 may be in the range up to about 0.250 inches. For a filter comprising a fibrous depth filter medium and a laid-over pleat configuration, such as that available from Pall Corporation under the trade designation Ultipleat™, the gap may be less than about 0.20 inches, and preferably the gap 34 may be about 0.05 inches.

The second end of the perforated support cage 14 may be completely open, may comprise a closed flat circular base, or, may comprise a flat annular flange which extends radially inward and upon which the filter element 12 may rest. In a preferred embodiment, the second end of the perforated support cage 14 comprises a flat annular flange 15. The second end of the perforated support cage 14 may comprise an orifice 36 through which a crud sump (not illustrated) may be attached to the filter element 12.

The perforated support cage 14 preferably comprises openings to permit the passage of fluid through the filter element 12 without creating any substantial

pressure differential across the support cage 14. The openings, however, are preferably small enough to prevent the filter medium from expanding into the openings and becoming trapped and/or damaged in the openings if the filter pack 16 expands from the pressure during filtration. For example, the openings in the perforated support cage 14 are circular in configuration and preferably smaller than 0.188 inches in diameter. The openings in the perforated support cage 14 may comprise any other suitable configuration, including square, rectangular, oblong, or elliptical. In addition, the openings may be larger than 0.188 inches in diameter if, for example, a fine mesh support is attached to the inner circumference of the perforated support cage 14 to prevent the medium from becoming trapped in the openings.

The perforated support cage 14 may comprise any material which has sufficient strength to withstand the forces generated by the fluid during filtration and which is compatible with the particular fluid being filtered. For example, the perforated support cage 14 may comprise metallic materials, such as stainless steel, or polymeric materials, such as polyphenylene sulfide. In a preferred embodiment, the perforated support cage 14 comprises stainless steel. The perforated support cage 14 may be attached to the tubesheet 26 in any number of ways, including welding and bolting. Alternatively, if the filters are oriented vertically, the perforated support cage 14 may simply rest upon the tubesheet 26.

Figure 2 is a sectional view of an alternative embodiment of the filter assembly of the present invention. In this embodiment, the filter assembly 10 comprises a support core 100 in addition to the perforated support cage 14. The support core 100 may comprise a substantially rigid structure which functions to prevent the filter pack from collapsing inward under the pressure of an inwardly directed flow of fluid. For example, the support core 100 may comprise a perforated cylinder formed from a rigid polymeric material, such as polypropylene, or a metal, such as stainless steel. Alternatively, the support core 100 may comprise a more pliable structure which merely functions to prevent the filter pack from collapsing inward from the forces generated during insertion of the filter element into the perforated support cage. For example, in the illustrated embodiment, the support core 100 comprises first and second dye springs.

A support core may be positioned around the inner periphery of the filter pack and a support cage may be positioned around the outer periphery of the filter pack. The loading conditions on the support core and the support cage may vary significantly. Typically, a support cage is utilized to provide support for the filter pack when fluid flow is from the inside to the outside of the filter pack. Consequently, the support cage may be subjected to tensile forces. A support core on the other hand is generally utilized to provide support for the filter pack when fluid flow is from the outside to the inside of the filter pack. Consequently, the support core may be subjected to compressive forces. Compressive force or loading is generally more destructive than tensile force or loading. Accordingly, a support core would preferably be heavier and thicker than a support cage to compensate for the more destructive forces. Therefore, providing a support cage and directing fluid flow inside out may be more desirable from a manufacturing cost perspective because the materials utilized are less expensive.

The perforated support cage 14, described in detail above, supports the filter element 12 in the opening of the tubesheet 26 and supports the filter element 12 against outwardly directed forces during filtration. The filter element 12, as indicated above, comprises the first end cap 20, the second end cap 22, and the filter pack 16. A detailed description of the second end cap 22, the first end cap 20, and the filter pack 16 is given below.

The second end cap 22 of the filter element 12 may be an open end cap or a blind end cap. An open end cap may be particularly advantageous for connecting filter elements 12 end to end to construct longer filter elements. Open end caps for connecting filter elements end to end are generally referred to as joiner caps. Longer filter elements offer certain advantages, as is discussed subsequently. The second end cap may comprise an opening that communicates with the crud sump (not illustrated) mentioned above. The opening would facilitate the removal of heavier particulates in the process fluid which otherwise might simply, due to gravity, collect at the lower end of the filter element 12. The crud sump may be useful in certain embodiments; however, there is the potential that the crud sump may create "dead zones" in the flow of fluids, such as highly viscous fluids, through the filter element 12. In a preferred embodiment, the second end cap 22 may be a blind end

cap.

Figures 3a and 3b are detailed top and sectional views of a blind second end cap 22, respectively. The second end cap 22 comprises a substantially circular configuration, e.g., a circular disc, with an outside diameter substantially equal to the outside diameter of the filter pack 16. The second end cap 22 also comprises a structure 38 which protrudes inwardly towards the center region of the filter element 12. This structure 38 directs the flow of fluid near the lower end of the filter element 12 radially outward through the filter pack 16. Accordingly, dead zones (stagnant fluid) in the fluid path may be significantly reduced. The structure 38 may comprise any suitable configuration, e.g., concave or conical, which will direct the flow of fluid towards the inner wall of the filter pack 16. In the exemplary embodiment illustrated in Figures 1 and 3b, the structure 38 generally comprises a hemispherical protrusion in a central region of the second end cap 22. The second end cap 22 comprises a substantially flat outer periphery 39 for mounting the second end cap 22 to the end of the filter pack 16.

The second end cap 22 may comprise any suitable fluid impervious material which is compatible with the particular process fluid being filtered and which will provide a fluid tight seal with the filter pack 16. For example, the second end cap 22 may comprise any impervious metals, ceramics, elastomers, or polymeric materials including glass fiber filled polypropylene. In an exemplary embodiment, the second end cap 22 comprises polypropylene.

The second end cap 22 may be thermally bonded, or spin welded to the end of the filter pack 16 to provide a strong, uniform seal. Other methods may be utilized for attaching the second end cap 22 to the end of the filter pack 16, including sonic welding, polycapping, or bonding by means of an adhesive or a solvent. In a preferred embodiment, the flat outer periphery 39 of the second end cap 22 may be spin welded to the filter pack 16. Accordingly, the second end cap 22 may include a plurality of spin lugs 23 which are utilized to spin the second end cap 22 by a device not illustrated.

In the filtration process, assuming inside to outside fluid flow, the process fluid flows through an opening in the first end cap 20 into a central region of the tubular filter element 12 at a specific flow rate and pressure. The process fluid in

this central region passes through the filter pack 16, including the filter medium, whereby contaminants in the process fluid are removed. While the flow rate remains substantially constant, there is typically a pressure differential between the process fluid on the upstream side of the filter pack 16 and the process fluid on the downstream side of the filter pack 16. This pressure differential results in forces acting upon the filter element 12 in both the radial and axial directions. The perforated support cage 14, as described above, and the wrap 18, as is explained subsequently, provide support for the filter pack 16 against the radially directed forces.

In accordance with one aspect of the invention, one or both of the end caps comprising the filter element 12 preferably allows the filter element 12 to move in the axial direction within the perforated support cage 14. Specifically, the end cap allows the filter element to move from an initial position within the support cage 14 in which one end of the filter element 12 is spaced from or is not in close contact with the second end of the support cage 14 to a final position in the support cage 14 in which one end of the filter element 12 is in proximity to or in contact with the second end of the support cage 14. A first end cap which allows the filter element to move in the direction of the axially directed forces and ultimately bottom out on the perforated support cage substantially reduces the axial or tensile forces acting on the filter element during filtration. The first end cap preferably also maintains a fluid tight seal between the filter element 12 and the tubesheet 26 and between the perforated support cage 14 and the tubesheet 26 to prevent process fluid by-pass between the filter element 12 and the tubesheet 26 or the support cage 14 while allowing the filter element 12 to move in the axial direction. Essentially, the seal arrangement has the largest outside diameter of the filter element 12. In particular, the seal arrangement has an outside diameter greater than the largest outside diameter of the filter pack 16. In addition, because the first end cap allows the filter element to move in the axial direction and eventually bottom out in the perforated support cage 14 while maintaining a fluid tight seal, the manufacturing tolerances on the filter element 12 may be relaxed. In conventional filter elements, the tolerances may be very exact in order to maintain a fluid tight seal; however, where an end cap which allows a filter element to move in the axial direction while maintaining a fluid

tight seal is utilized, the tolerance may be relaxed.

For filter elements 12 which may be utilized with perforated support cages 14 that may be removably mounted to the tubesheet 26, the first end cap may preferably comprise a seal arrangement such as a face seal which seals the filter element 12 to the tubesheet 26 to prevent fluid by-pass while allowing axial movement of the filter element 12 in the perforated support cage 14. This design facilitates installation and removal of the filter element 12 from the perforated support cage 14 without pulling the cage 14 away from or out of the tubesheet 26, thereby eliminating the need to further disassemble the support cage 14 from the removed filter element 12.

In an exemplary embodiment, the first end cap 20 may be an open end cap having a structure which preferably allows the filter element 12 to move in the axial direction within the perforated support cage 14. Specifically, the first end cap 20 allows the filter element 12 to bottom out on the perforated support cage 14 during filtration, i.e., the second end cap 22 moves to a position proximate with or contacts the flange 15 at the second end of the perforated support cage 14, thereby reducing the tensile forces acting upon the second end cap 22, the first end cap 20, and the filter pack 16 by transferring the forces from the filter element 12 to the perforated support cage 14. As stated above, reducing the forces acting on the filter element 12 decreases the likelihood of the filter element 12 developing defects, and increases the useful life of the filter element 12. Specifically, reducing the forces acting on the filter element 12 decreases the chances that the filter medium will be damaged and develop a defect, for example, a fluid by-pass between the first and second end caps 20, 22 and the filter pack 16.

An end cap which allows for the axial movement of the filter element may be variously configured, for example, as an extendable end cap or a slidable end cap. In Figure 1, the filter element 12 is illustrated as bottomed out on the perforated support cage 14 with the first end cap 20 providing a fluid tight seal between the filter element 12, the perforated support cage 14, and the tubesheet 26, and the first end cap 20 is extendable. An extendable end cap may be variously configured. For example, Figures 4a and 4b are detailed top and sectional views of the one embodiment of an extendable end cap 20. In a preferred embodiment, the first end

cap 20 comprises three segments. The first segment 40 may be mounted to the filter pack 16, thereby moving with the filter pack 16. The second segment 42 includes a first section 44 that is slidably arranged with the first segment 40, and a second section 46 that rests upon the support cage 14 or, more preferably, upon the tubesheet 26 to provide a fluid tight seal therewith. The third segment 48 may be attached to the first segment 40 to secure the second segment 42 in slidable engagement with the first segment 40.

The first segment 40 preferably comprises a substantially cylindrical configuration having an outside diameter substantially equal to the outside diameter of the filter pack 16, including the wrap 18. The first segment 40 includes a substantially flat section 50 with an axially directed lip 52 for mounting the first segment 40 of the first end cap 20 to an end of the filter pack 16, and an annular channel 54 in which the first section 44 of the second segment 42 is slidably disposed. The substantially flat section 50 has an inside diameter and the lip 52 has an outside diameter which are substantially equal to the inside diameter of the filter pack 16. The substantially flat section 50 may be attached to a first end of the filter pack 16 while the lip 52 may be in intimate contact with a portion of the inner surface of the filter pack 16. The lip 52 may be attached to the inner surface of the filter pack 16, or preferably, the lip 52 may simply make contact with the inner surface of the filter pack 16. The lip 52 may comprise a tapered end 53. The tapered end 53 facilitates the attachment of the top end cap 20 to the filter pack 16.

The annular channel 54 is formed by two protrusions 55 and 57 extending perpendicularly from the flat section 50. The outer protrusion 57 preferably extends further than the inner protrusion 55. However, the inner protrusion 55 preferably comprises a plurality of weld stakes 59. Figure 5 is a detailed illustration of a single weld stake 59. The weld stakes 59, as is explained in detail subsequently, are utilized to connect the third segment 48 to the first segment 40. Alternatively, the two protrusions 55 are 57 may be of equal length and other means for attachment utilized.

The first segment 40 may comprise any suitable fluid impervious material which is compatible with the particular process fluid being filtered and which will

provide a fluid tight seal with the filter pack 16. For example, the first segment 40 may comprise any impervious metals, ceramics, elastomers, or polymeric materials, including glass fiber filled polypropylene. In an exemplary embodiment, the first segment 40 comprises polypropylene.

The first segment 40 may be thermally bonded, or spin welded to the end of the filter pack 16 to provide a strong uniform seal. Other methods may be utilized for attaching the first segment 40 to the filter pack 16, including sonic welding, polycapping or bonding by means of an adhesive or a solvent. In the preferred embodiment, the first segment 40 is spin welded to the filter pack 16. Accordingly, the first segment 40 includes a plurality of spin lugs 61 which are utilized to spin the first segment 40, as described previously with respect to the spin welding of the second end cap 22 to the filter pack 16. The first segment 40 may be attached to the end of the filter pack 16 prior to final assembly of the first end cap 20 or after the end cap 20 is assembled. In a preferred embodiment, the first segment 40 may be attached to the end of the filter pack 16 prior to final assembly of the first end cap 20.

The second segment 42 comprises a substantially cylindrical overall configuration and includes the first and second sections 44, 46. The outside diameter of the second section 46 of the second segment 42 may be greater than the outside diameter of the tapered section 28 of the support cage 14 and greater than the diameter of the opening in the tubesheet 26 through which the filter element 12 is disposed. Accordingly, the second section 46 of the second segment 42 of the top end cap 20 provides a fluid-tight seal between the filter element 12, the perforated support cage 14, and the tubesheet 26, as well as the tubesheet 26 to the vessel or housing cover as is explained subsequently. The second section 46 comprises a sealing arrangement or structure 47, i.e., a face seal, having any suitable sealing configuration, e.g., a substantially triangular cross-section, in sealing contact with the shoulder region 32 of the tubesheet 26. As illustrated, the sealing structure 47 has the largest outside diameter of the filter element 12. In particular, the sealing structure 47 has an outside diameter greater than the largest outside diameter of the filter pack 16. Other configurations for the sealing structure 47 may be utilized, including a spherical configuration. The sealing structure 47 may be positioned on

the shoulder region 32 of the tubesheet 26 such that an edge of the sealing structure makes contact with the shoulder 32, i.e., small surface area rather than a large surface area for increased pressure.

The sealing structure 47 may be energized, i.e., provide the fluid tight seal, by any suitable arrangement for clamping the filter element 12 to the tubesheet 26, e.g., by a housing cover of the filtration system (not illustrated). The housing cover may be variously configured. For example, the housing cover may comprise a flat plate having openings corresponding to the openings in the tubesheet 26 or it may comprise a grid having a multiplicity of smaller openings. When the housing cover is closed, the plate or grid presses each filter element 12 against the tubesheet 26, and the compressive forces generated energize the sealing structure 47, thereby establishing the fluid tight seal. The fluid tight seal is the result of the deformation of the sealing structure 47 due to the pressure at the point of contact between the sealing structure 47 and the tubesheet 26. Therefore, since the edge of the sealing structure makes contact with the shoulder 32, the pressure is greater than if a flat surface were utilized and a better seal is formed. The seal may be further energized or enhanced by the compression fit of the first section 44 in the annular channel 54, as is explained in detail subsequently. The housing cover may be secured in position by various means including bolts and latches.

The sealing structure 47 may be additionally energized by the forces generated by the process fluid during filtration. Specifically, the forces generated by the process fluid will tend to force the filter element 12 towards the second end of the perforated support cage 14, thereby possibly further compressing the sealing structure 47. However, the primary energizing mechanism is the arrangement which clamps the filter element to the tubesheet 26.

The first section 44 of the second segment 42 of the first end cap 20 preferably comprises a substantially L-shaped cross-section and is positioned in the annular channel 54 of the first segment 40. The first section 46 may be in intimate contact with the protrusions 55 and 57 of the annular channel 54, but preferably slides within the annular channel 54 so that the first end cap 20 may extend and the filter element 12 may move between a position removed from the closed end of the support cage 14 to a position in proximity to or in contact with the second end of the

perforated support cage 14, as illustrated in Figure 1.

The L-shaped first section 44 provides a substantially fluid tight seal between itself and the protrusions 55 and 57 comprising the annular channel 54. This seal may be energized by a compressive interface fit in the annular channel 54 and enhanced by the forces generated by the process fluid during filtration. The L-shaped first section 44 is larger than the opening defined by the annular channel 54. Consequently, when the L-shaped first section 44 is positioned in the annular channel 54, the seal is energized by the compressive forces acting upon the first section 44. In addition, the flow of process fluid forces the L-shaped first section 44 into intimate contact with the outer protrusion 57 if the flow of process fluid is inside to outside. If, however, the flow of process fluid is outside to inside, the L-shaped first section would be forced in intimate contact with the inner protrusion 55. The first section 44 may comprise other cross-sectional shapes, for example, T-shaped or spherical shaped.

The second segment 42 may comprise any fluid impervious material which is compatible with the particular process fluid being filtered, and which will provide a fluid tight seal. For example, the second segment 42 may comprise any material suitable for sealing including impervious metals, ceramics, elastomers, thermoplastic elastomers, or polymeric materials. In an exemplary embodiment, the second segment 42 comprises a thermoplastic elastomeric material available under the trade name Santoprene®.

The third segment 48 comprises an annular ring positioned over an upper region of the annular cavity 54 of the first segment 40. The third segment 48 secures the first section 44 of the second segment 42 in the annular channel 54 of the first segment 40. The third segment 48 may be positioned and secured to the upper region of the annular channel 54 by any number of bonding methods and may be formed out of any suitable fluid impervious material which is compatible with the particular process fluid and which maintains the first section 44 in the annular channel 54. In a preferred embodiment, the third segment 48 comprises a polymeric material such as polypropylene.

Figures 6a and 6b are detailed top and sectional views of the third segment 48 of the first end cap 20. As illustrated, the third segment 48 comprises an annular

ring. In a preferred embodiment, the third segment 48 comprises a plurality of openings 63 which correspond to the plurality of weld stakes 59 on the inner protrusion 55 of the first segment 40. The third segment 48 rests upon the inner protrusion 55 of the annular channel 54. The weld stakes 59 which protrude through the openings 63 in the third segment 48, once heated, melt and weld the third segment 48 to the first segment 40. Since the third segment 48 is mounted to the inner protrusion 55, and not the outer protrusion 57, the second segment 42 is free to move within the annular channel 54. Other means for attachment of the third segment 48 may be utilized.

The third segment 48 preferably has an inside diameter which corresponds to an inside edge of the inner protrusion 55 and an outside diameter which is in proximity to the L-shaped first section 44 of the second segment 42. Accordingly, the third segment 48 secures the L-shaped first section in the annular channel 54 of the first segment 40.

The third segment 48 facilitates the easy insertion of the second segment 42 into the first segment 40. Until the third segment 48 is welded or otherwise joined to the first segment 40, the second segment 42 may be removed and/or replaced. For example, depending upon the particular application, differently configured second segments 48 may be utilized. The second segments 48 may typically have the same inside diameter so that they maintain a specific relationship with the first segment 40, but the outside diameter may vary depending upon the diameter of the opening in the tubesheet 26. In one instance, for example, the tubesheet 26 may have a larger opening than required for the filter assembly; accordingly, a larger second segment 42 may be required to provide an adequate fluid tight seal as described above. The larger opening in the tubesheet 26 may have been designed because the previous filters utilized may have been larger to achieve the equivalent filtration surface area for the particular application. Consequently, because of the modular design of the first end cap 20, the filter assembly of the present invention may be utilized in a wide range of filter systems having any number of configurations.

The handle 24 illustrated in Figures 1, 2, 4a and 4b, as stated above, may be utilized to insert or remove the filter element 12 from the perforated support cage

14. The filter element 12 may be removed from the perforated support cage 14 by the handle 24 without removing the perforated support cage 14 from the tubesheet 26 because the first end cap 20 provides a seal with the tubesheet 26 and not the perforated support cage 14 and because of the small gap 34. Because of the gap 34 between the perforated support cage 14 and the filter element 12, there is preferably little or substantially no resistance to the insertion of a new or unused filter element 12 into the perforated support cage 14. Likewise, there is preferably little or substantially no resistance to the removal of a new or unused filter element 12 from the perforated support cage 14. Although there may be some minimal resistance to movement due, for example, to deviations in manufacturing tolerances, the filter element 12 may be removed by the handle 24 without removing the perforated support cage 14 from the tubesheet 26.

The handle 24 may be connected to the first end cap 20 by any suitable means including bonding or welding. Alternatively, the handle 24 may be formed as an integral component with the first segment 40 of the first end cap 20. Alternatively, or in addition, a rigid structure such as a tie rod (not illustrated) may be utilized. The tie rod would extend between and connect the first and second end caps 20, 22, thereby fixedly spacing the end caps 20, 22 from one another and providing additional strength for the filter element 12.

Once the filter element 12 has been utilized in a filtration process, the filter medium may have expanded due, for example, to the swelling of the medium or more likely because of the forces generated by the fluid flow. Accordingly, the gap 34 that did exist when the new or unused filter element was inserted into the support cage may no longer exist. If there is no gap 34, there may be a non-negligible resistance to axial movement of the filter element 12 in the perforated support cage 14. Preferably, the diameter of the filter element 12 only increases by a maximum of about fifteen percent. The minimal resistance to movement of a used filter element 12, for example, one which has expanded against the perforated support cage 14, may be easily overcome because the gap 34 may allow the filter element 12 to expand without becoming tightly wedged against the inner wall of the perforated support cage 14 or within the perforations of the support cage 14. In addition, as stated above, the first end cap 20 seals to the tubesheet 26 and not the perforated

support cage 14. Consequently, the filter element 12 may be removed from the perforated support cage 14 by the handle 24 without removing the support cage 14 from the tubesheet 26. In filter assemblies having perforated support cages 14 permanently attached to the tubesheet 26, end caps which seal to the perforated support cage 14 may be utilized since there is no concern that the perforated support cage 14 will detach from the tubesheet 26.

The filter element 12 also comprises the filter pack 16. The filter pack 16 may be variously configured for any particular application. For example, the filter pack 16 may comprise a porous mass having a disc-shaped, hollow or solid cylindrical configuration, or it may comprise a pleated configuration which has radially extending pleats or pleats in a laid-over configuration.

Figure 7 illustrates an exemplary embodiment of a portion of a filter element 12 comprising a pleated filter pack 16 and a retainer, such as a wrap 18. In an exemplary embodiment, the filter pack 16 is generally cylindrical in configuration and comprises a plurality of longitudinal pleats 56 which are preferably in a laid-over state. As illustrated in Figures 8 and 9, each pleat 56 has two legs 58 which are joined to one another at a crown 60 at the outer periphery of the filter pack 16 and which are joined to a leg 58 of an adjacent pleat 56 at a root 62 at the inner periphery of the filter pack 16. Each leg 58 has an internal surface 64 which opposes the internal surface 64 of the other leg 58 in the same pleat 56, and an external surface 66 which opposes the external surface 66 of a leg 58 of an adjacent pleat 56. When the filter element 12 is being used such that fluid flows radially inward through the filter element 12, the internal surfaces 64 of the legs 58 form the downstream surface of the filter pack 16, while the external surfaces 66 form the upstream surface of the filter pack 16. Alternatively, when the filter element 12 is being used such that fluid flows radially outward through the filter element 12, the internal surfaces 64 and the external surfaces 66 respectively form the upstream and downstream surfaces of the filter pack 16.

As illustrated in the figures, the opposing internal surfaces 64 of the legs 58 of each pleat 56 are preferably in intimate contact with one another over substantially, i.e., a large portion of, the entire height (h) of the pleat 56, and over a continuous region extending for a significant portion of the axial length of the filter

pack 16. In addition, the opposing external surfaces 66 of the legs 58 of adjacent pleats 56 are preferably in intimate contact over substantially, i.e., a large portion of, the entire height of the adjacent pleats 56, and over a continuous region extending for a significant portion of the axial length of the filter pack 16. Here the height h (shown in Figure 8) of the pleats 56 is measured in a direction along the surfaces of the legs 58 and extends from the inner periphery to the outer periphery of the filter pack 16. The condition illustrated in Figures 8 and 9 in which the surfaces of the legs 58 of the pleats 56 are in intimate contact and in which the height h of each pleat 56 is greater than the distance between the inner and outer peripheries of the filter pack 16 (i.e., [D-d]/2 in Figure 8) will be referred to as a laid-over state. In the laid-over state, pleats may extend, for example, in an arcuate or angled fashion or in a straight, non-radial direction. There is preferably substantially no empty spaces between adjacent pleats, and virtually all of the volume between the inner and outer peripheries of the filter pack 16 may be occupied by the filter pack 16 and can be effectively used for filtration.

Because the filter pack 16 is formed from a material having a finite thickness (t) at the radially inner and outer ends of the pleats 56 where the filter pack 16 is folded back upon itself to form the pleats 56, the pleats 56 may be somewhat rounded. As a result, at the radially inner ends of the pleats 56, small substantially triangular gaps may be formed between the opposing internal surfaces of adjoining legs, and at the radially outer ends of the pleats 56, small substantially triangular gaps 70 may be formed between the opposing external surfaces 66 of adjoining legs 58 or between the internal surfaces of the legs of a pleat. However, in the present invention, the height of these gaps 68 and 70 as measured along the height of the pleats 56 is preferably extremely small. The height of the gaps 68 and 70 adjoining the inner diameter of the filter is preferably no more than approximately t and more preferably no more than approximately ½t, wherein t is the thickness of the material forming the filter pack 16, as illustrated in Figure 8. The height of the gaps 68 and 70 adjoining the outer diameter of the filter pack 16 is preferably no more than approximately 4t and more preferably no more than approximately 2t. As the pleats 56 are made sharper, i.e., the radially inner and outer ends thereof less rounded, the heights of the gaps 68 and 70 becomes smaller and the percentage of the volume

between the inner and outer peripheries of the filter pack 16 which is available for filtration becomes greater.

The opposing surfaces of adjoining legs 58 of the pleats 56 need not be in intimate contact over a substantial portion of the axial length of the filter pack 16, but the greater the length in the axial direction of the region of intimate contact, the more effectively the space between the inner and outer periphery of the filter pack 16 is used. Therefore, adjoining legs 58 are preferably in intimate contact over a continuous region which extends for at least approximately 50%, more preferably at least approximately 75%, and most preferably approximately 95 to 100% of the axial length of the filter pack 16. The laid-over pleat configuration is described in PCT publication PCT/US93/10697, which is incorporated by reference herein.

The filter pack 16 preferably includes at least one layer of a filter medium and may further include drainage means disposed on at least one side, preferably the upstream side, and more preferably on both the upstream and downstream sides of the filter medium. The drainage means enables fluid to evenly flow to or from substantially all portions of the surface of the filter medium when the pleats 56 are in the laid-over state. Thus, virtually the entire surface area of the filter medium may be effectively used for filtration. Essentially, the drainage means facilitates edgewise or lateral fluid flow.

The filter pack 16 may comprise a single layer or multiple layers. The type and numbers of layers utilized may vary depending on the particular application. In the exemplary embodiment of Figure 8, and as illustrated in detail in Figure 10, the filter pack 16 preferably comprises a five-layer composite comprising two layers of filter media 72, 74, upstream drainage means in the form of an upstream drainage layer 76 disposed upstream of the filter media 72, 74, a cushioning layer 78 disposed between the upstream drainage layer 76 and the filter media 72, 74, and downstream drainage means in the form of a downstream drainage layer 80 disposed on the downstream surface of the filter media 72, 74.

There are no particular restrictions on the type of filter medium which may be employed in the present invention, and it may be selected in accordance with the fluid which is to be filtered and the desired filtering characteristics. The filter medium may be used to filter fluids such as liquids, gases, or mixtures of liquids,

gases, and solids. The filter medium may comprise fibrous materials such as a mass of fibers, fibrous mats, woven or non-woven fibrous sheets, and fibrous depth filters; semi-permeable or porous membranes such as supported or non-supported microporous membranes; porous foam; and porous metals or ceramics. The filter medium may have a uniform or graded pore structure and any appropriate effective pore size. The filter medium may be formed from any suitable material, such as a natural or synthetic polymer, glass, or metal. The filter medium may comprise a single layer, or a plurality of layers of the same medium may be disposed atop one another to a desired thickness. Furthermore, it is possible for the filter medium to include two or more layers having different filtering characteristics, e.g., with one layer acting as a prefilter for the second layer.

In a preferred embodiment, the filter medium comprises a fibrous depth filter medium. For example, the depth filter medium may comprise meltblown fibers composed of any suitable polymer, including polypropylene, polyester or TPX. Alternatively, the filter medium may comprise glass fibers, for example, glass fibers deposited on a suitable substrate. The depth filter medium may have a constant or a graded pore structure. The graded pore structure is particularly effective in the removal of solids from highly viscous fluids such as paints. For example, the graded pore structure may include an upstream section having large pores and formed from large diameter fibers and a downstream section having finer pores and formed from smaller diameter fibers. The transition from the upstream section to the downstream section may be gradual, e.g., by means of progressively smaller diameter fibers, or abrupt. Alternatively, the depth filter medium may comprise a graded pore upstream section and a constant pore downstream section.

The upstream and downstream drainage layers 76 and 80 may be made of any materials having suitable edgewise flow characteristics, i.e., suitable resistance to fluid flow through the layer in a direction parallel to its surface. The edgewise flow resistance of the drainage layer is preferably low enough that the pressure drop in the drainage layer is less than the pressure drop across the filter medium, thereby providing an even distribution of fluid along the surface of the filter medium. The drainage layers 76, 80 may be in the form of a mesh or screen or a porous woven or non-woven sheet. Meshes are particularly suitable as drainage layers when the filter

medium is a fibrous medium. On the other hand, when the filter medium is a porous membrane, a woven or non-woven fabric may be more suitable for use as the drainage layer because a fabric is usually smoother than a mesh and produces less abrasion of adjoining layers of the filter composite. An example of a suitable non-woven fabric for use as a drainage layer is a polyester non-woven fabric sold under the trade designation Reemay 2011 by Reemay, Inc.

Meshes and screens (also called netting) come in various forms. For high temperature applications, a metallic mesh or screen may be employed, while for lower temperature applications, a polymeric mesh may be particularly suitable. Polymeric meshes come in many forms, e.g., woven meshes, expanded meshes, and extruded meshes. Any type may be employed, but extruded meshes are generally preferable because they are smoother and therefore produce less abrasion of adjoining layers of the filter composite. An extruded mesh may have a first set of parallel strands extending in one plane and a second set of parallel strands extending in another plane and intersecting the first set of strands at an angle.

Meshes may be characterized, for example, by their thickness and by the number of strands per inch. The thickness is not limited to any particular values and can be chosen in accordance with the desired edgewise flow characteristics of the mesh and the desired strength. Preferably, at least one set of strands of the mesh, e.g., the set of strands nearer the filter medium, will have a mesh count of at least ten (10) strands per inch.

In an exemplary embodiment of the present invention, the opposing surfaces of the pleats are preferably in intimate contact. Consequently, the strands of the drainage mesh of each leg of the pleats are pressed against the strands of the drainage mesh of an adjacent leg of the pleats. If the strands of the mesh on two opposing surfaces are parallel to one another, the strands may have a tendency to "nest", i.e., to fit between one another rather than to lie atop one another. This degrades the drainage properties of the mesh and decreases its ability to provide drainage for the filter medium. Consequently, the strands of the mesh are preferably arranged to avoid nesting.

The upstream and downstream drainage layers may be of the same or different construction. It has been found that the pressure drop across the filter

medium may be lowest and filter life may be longest when both the drainage layers have substantially the same edgewise flow resistance. Therefore, regardless of whether the drainage layers are made of the same material, they are preferably selected so as to have substantially the same resistance to edgewise flow. For ease of manufacture, it is convenient to use identical materials for both drainage layers, thereby assuring the same edgewise flow resistance through the drainage layers.

The composite forming the filter pack 16 may include other layers in addition to the filter medium and the drainage layers. For example, in order to prevent abrasion of the filter medium due to rubbing contact with the drainage layers when the pleats expand and contract during pressure fluctuations of the fluid system in which the filter is installed, a cushioning layer may be disposed between the filter medium and one or both of the drainage layers. The cushioning layer is preferably made of a material smoother than the drainage layers and having a higher resistance to abrasion than the filter medium. For example, when the drainage layers are made of a mesh, an example of a suitable cushioning layer is a polyester non-woven fabric such as that sold under the trade designation Reemay 2250 by Reemay Corporation.

The layers forming the filter pack 16 may be formed into a composite by conventional filter manufacturing techniques, either prior to or simultaneous with corrugation.

The filter element 12 may be provided with a retainer such as a wrap or sleeve to enhance the resistance of the filter pack 16 against outwardly directed forces and/or to retain the pleats in a laid-over state. In a preferred embodiment, the filter element 12 comprises a wrap 18 to provide support for the filter medium and to retain the pleats in a laid-over state. For example, the hoop strength of the wrap 18 may enable the filter pack 16 to better resist circumferential stresses. In addition, the wrap 18 may serve to protect and support the filter pack 16 during manufacture, installation, and maintenance. The wrap may comprise one or more strips wrapped at least once around the filter pack and may be bonded to the filter pack and/or the top and bottom end caps. In the exemplary embodiment illustrated in Figure 8, the wrap 18 comprises a helical wrap comprising a parallel-sided strip of a flexible material which is helically wrapped about the filter pack 16

in a plurality of turns. The wrap 18 may be made of any material which is compatible with the fluid being filtered. If the wrap 18 completely envelops the outer periphery of the filter pack 16, the wrap 18 is preferably porous. For many applications, a porous, polymeric, non-woven material available from Reemay Corporation under the trade designation Reemay is suitable. Laminates of the Reemay material may also be employed. However, the wrap 18 may be formed from any suitable material which will enhance the structural integrity of the filter, increase the resistance to outwardly directed force, and maintain the filter medium in a laid-over pleat configuration.

The wrap 18 is not limited to a single strip of material. For example, the wrap 18 may comprise two strips of material wrapped around the filter pack 16 in a double helix. Alternatively, the wrap 18 could be wrapped around the filter pack 16 in the circumferential direction rather than the helical direction. In a preferred embodiment, the wrap 18 may be attached to the filter pack 16 in accordance with the process described in PCT publication PCT/US93/10697, which has been incorporated by reference herein.

The extendable end cap may be configured in any other suitable manner. For example, rather than having segments which slide along one another as illustrated in Figure 4(b), the extendable end cap may comprise a foldable or stretchable segment. For example, as illustrated in Figures 11(a) and 11(b), the first end cap 150 may include a first segment 151 attached to the filter pack 116 and a second segment 152 attached to the first segment 151 and comprising a seal arrangement such as a flexible flange seal which is foldable and/or stretchable, thereby allowing the filter element 112 to bottom out on the perforated support cage 154 while maintaining a fluid tight seal. The flexible flange seal may comprise a sealing lip on an underside of the seal to provide the fluid tight seal. As in the previously described embodiment, the flexible flange seal preferably has the largest outside diameter of the filter element 12. In particular, the sealing structure has an outside diameter greater than the largest outside diameter of the filter pack 116. The sealing lip may be energized by any suitable arrangement for clamping the filter element 112 to the tubesheet 126. Any of the arrangements discussed above in regard to the filter assembly of Figure 1 may be utilized to energize the seal. The second segment 152

rests upon a shoulder region 153 of the first segment 151. The first and second segments 151 and 152 may comprise any suitable materials. For example, the first segment 151 may comprise polypropylene and the second segment 152 comprises an elastomeric or thermoplastic elastomeric material available under the tradename Santoprene®. The first and second segments 151, 152 may be secured to each other utilizing any number of techniques including welding and bonding. Alternatively, the first and second segments 151, 152 may be a single unitary structure. In a preferred embodiment, the first and second segments 151, 152 are comolded.

The filter assembly illustrated in Figures 11a and 11b further comprises a modified perforated support cage 154 in addition to a modified first end cap 150. The modified perforated support cage 154 comprises a substantially cylindrical configuration. A first end of the perforated support cage 154 is open so that the filter element may be disposed within the perforated support cage 154. A second end of the perforated support cage 154 may be blind or open. In a preferred embodiment, the second end is blind. The blind end may comprise a flat disc or a disc comprising the structure of the disc illustrated in Figure 1. In the exemplary embodiment, the blind end comprises a flat disc mounted to the end of the perforated portion of the support cage 154 by welding or the like.

The perforated support cage 154 may be attached to the tubesheet 126 by any suitable means. In the exemplary embodiment, the upper end of the perforated support cage 154 comprises a support structure 160 including a tapered section 161, a straight section 162 and a flange 163 for securing the perforated support cage 154 to the tubesheet 126. The flange 163 rests upon an annular lip 164 in the tubesheet 126. The flange 163 may be permanently attached to the tubesheet 126 or may simply rest upon the annular lip 164. The perforated support cage 154 may be connected to the support structure 160 by any suitable means including welding or bonding.

The second segment 152 of the first end cap 150 conforms to the support structure 160 when the filter element 112 bottoms out on the perforated support cage 154. As illustrated, the second segment 152 preferably has a larger outer diameter than the flange 163 and maintains a seal over the tubesheet 126 and the perforated support cage 154 to prevent fluid by-pass. This seal is maintained

regardless of the position of the filter element 112. When the end of the filter element 112 is above, i.e., not in proximity to or not in contact with. the bottom of the perforated support basket 154, a portion of the second segment 152 folds as illustrated in Figure 11a; however, when the filter element 112 bottoms out. the folded portion conforms to the tapered section 161 of the support structure as illustrated in Figure 11b.

The second end cap 170 may be an open end cap or a blind end cap and comprise any suitable configuration such as a flat disc or an annular disc having a hemispherical protrusion in a central region thereof as in the embodiment described above. In a preferred embodiment, the second end cap 170 is a blind end cap, and as illustrated in Figures 11a and 11b, the blind end cap 170 comprises a flat disc. The second end cap 170 may comprise any suitable fluid impervious material which is compatible with the particular process fluid being filtered and which will provide a fluid tight seal. The second end cap 170 may be attached to the end of the filter pack 116 by any suitable means including spin welding.

The filter medium utilized to form the filter pack 116 may comprise any suitable material, and preferably comprises the fibrous depth filter medium described above in regard to the filter of Figure 1. In addition, each component, feature, or subset of components or features of the above described second embodiment and illustrated in Figures 11(a) and 11(b) may be combined with one or more of the components, features, or subsets of components or features of the first embodiment illustrated in Figures 1-10, or vice versa, without departing from the scope of the invention.

In an alternative embodiment, particularly well suited for support cages that are permanently attached to the tubesheets, the first end cap may comprise a sliding end cap for allowing the filter element to bottom out on the perforated support cage. Figure 12 is a sectional view of a portion of a preferred embodiment of the filter of the present invention. The filter 200 comprises a filter element 212 removably mounted in a perforated support cage 214. The filter element 212 includes a pleated filter pack 216, a retainer, such as a wrap 218, a first end cap 220, and a second end cap 222. In addition, the filter element 212 may also comprise a handle and/or a core (not illustrated). The filter may be disposed in an opening in

a tubesheet 226 of a filtration system. supported therein by the perforated support cage 214 and sealed to the tubesheet 226 by the first end cap 220. Any suitable hold-down structure may be utilized to secure the filter element 212 within the opening of the tubesheet 226. In a preferred embodiment, a grid plate is utilized to hold-down and secure the filter element 212 in position. The grid plate is positioned atop the tubesheet and may comprise a plurality of openings through which the fluid to be filtered may pass.

The first end cap 220, as stated above, comprises a sliding structure. In an exemplary embodiment, the first end cap 220 is an open end cap having a sealing structure or arrangement which allows the filter element 212 to move in the axial direction within the perforated support cage 214. In a preferred embodiment, the first end cap 220 comprises a substantially cylindrical configuration which preferably has an outside diameter at least slightly greater than the outside diameter of the filter pack 216. The first end cap 220 has a diameter slightly greater than the outside diameter of the filter pack 216 to allow the filter pack 216 to be inserted through the opening in the tubesheet 226 and yet provide a fluid tight seal between the first end cap 220 and the tubesheet 226 in which the filter assembly is positioned. The first end cap 220 may be designed to engage the tubesheet 226 in frictional engagement, thereby allowing axial movement of the filter element 212 while providing a fluid tight seal.

Although a slidable end cap may be configured in a variety of ways, in the illustrated preferred embodiment the first end cap 220 includes a seal arrangement which has a channel 228 circumferentially arranged in the outer periphery thereof. An O-ring seal 230 may be positioned in the channel 228. The O-ring seal 230 has an outside diameter slightly larger than the outside diameter of the top end cap 220. In addition, as in the previously described embodiments, the sealing structure or arrangement has the largest outside diameter of the filter element 212. In particular, the sealing structure or arrangement has an outside diameter greater than the outside diameter of the filter pack 216. The O-ring seal 230 allows for the axial movement of the filter element 212 in the perforated support basket 214 in addition to providing a fluid tight seal between the filter element 212, the perforated support basket 214 and the tubesheet 226 to prevent fluid by-pass. Essentially, the O-ring

seal 230 frictionally engages a seat arrangement 231 of the tubesheet 226 thereby providing a piston-type fluid tight seal. However, the frictional engagement is not strong enough to prevent axial movement of the filter element 212 due to the influence of the forces generated during filtration as is explained above, thereby allowing movement of the filter element 212 in the support cage 214. In having a slidable end cap 220 with an O-ring seal 230 such that the slidable end cap 220 is at the top of the filter element 212, the O-ring seal 230 may be easily inspected. The first end cap 220 also comprises a shoulder section 234 which engages a corresponding shoulder section 232 of the tubesheet 226 when the filter element 212 is bottomed out and functions as a stop. Alternatively, the shoulder section 234 of the first end cap 220 and the shoulder section 232 of the tubesheet 226 may be arranged such that there is a small gap therebetween when the filter element 212 is bottomed out, thereby allowing for limited compression of the filter element 212.

The first end cap 220 may comprise any suitable fluid impervious material which is compatible with the particular process fluid being filtered and which will provide a fluid tight seal. For example, the first end cap 220 may comprise any impervious metal, ceramic, elastomer or polymeric materials, including glass fiber filled polypropylene. In an exemplary embodiment, the first end cap 220 comprises polypropylene. The O-ring seal 230 may comprise any fluid impervious material which is compatible with the particular process fluid being filtered which provides a fluid tight seal. In the preferred embodiment, the O-ring seal may comprise an elastomeric or thermoplastic elastomeric material such as the one available under the trade name Santoprene®.

The first end cap 220 may be thermally bonded, or spin welded to the end of the filter pack 216 to provide a strong uniform seal. Other methods may be utilized for attaching the first end cap 220 to the filter pack 216, including sonic welding, polycapping or bonding by means of an adhesive or a solvent. In the preferred embodiment, the first end cap 220 is spin welded to the filter pack 216. Accordingly, the first end cap 220 may include a plurality of spin lugs (not illustrated) which are utilized to spin the top end cap 220 as described previously.

The tubesheet 226 comprises an opening having a diameter substantially equal to the diameter of the first end cap 220. The seal arrangement of the end cap

220 slidably engages the seat arrangement 231. The seat arrangement 231 defines an annular chase region 233 in which the seal arrangement of the first end cap 220 may travel in the axial direction. The length of the annular chase region 233 determines the length of axial movement of the filter element 212. Accordingly, since the O-ring seal 230 has a slightly larger diameter than the first end cap 220, the O-ring seal 230 frictionally engages the seat arrangement 231 in the annular chase region 233 thereby providing some resistance to the axial movement of the filter element 212 as well as providing the fluid tight seal. This resistance provides for the controlled movement of the filter element 212 within the perforated support basket 214 during filtration until the filter element 212 bottoms out in the perforated support basket 214 or until the shoulder sections 232,234 contact one another, as described previously. As stated above in the description of the previous embodiments, the axial movement of the filter element 212 reduces the tensile forces on the filter element 212 and transfers them to the support cage 214 which is better suited to handle the load.

The perforated support cage 214 is similar to the perforated support cage 14 illustrated in Figure 1 in that it comprises a substantially cylindrical configuration. Unlike the perforated support cage of Figure 1, the perforated support cage 214 of the embodiment illustrated in Figure 12 comprises an upper end which is straight rather than tapered. The straight end may be permanently attached to the tubesheet 226 under the shoulder 232 serving as the stop for the chase region 233 by any suitable means, e.g., welding. In a preferred embodiment, the perforated support cage 14 comprises stainless steel.

Each component, feature, or subset of components or features of the above described embodiment and illustrated in Figure 12 may be combined with one or more of the components, features, or subsets of components or features of the previously described embodiments illustrated in Figures 1-11 or vice versa, without departing from the scope of the invention.

Another exemplary filter assembly of the present invention generally comprises a hollow, tubular filter element, including a filter pack and two end caps, and a perforated support cage in which the filter element may be removably mounted. Each component, feature, or subset of components or features of the

above described embodiments may be combined with one or more of the components, features, or subsets of components or features of the present embodiment without departing from the scope of the invention. In this embodiment, at least one of the end caps may be designed to facilitate with substantially reduced resistance, even resistance free, insertion and removal of the filter element to and from the perforated support cage and to maintain a fluid tight seal between itself and the perforated support cage and/or the tubesheet opening in which the filter assembly is mounted during operation. Ease of insertion and removal may be achieved by an end cap, including a sealing structure, designed to provide a seal with a sealing surface such as a tubesheet or perforated support cage when the end cap is compressed, for example, by an external clamping arrangement. However, when the end cap is not compressed, the seal is relaxed and the filter element may be easily inserted or removed from the tubesheet and/or cage with minimal friction. In a preferred embodiment, the filter element rests upon the support cage, i.e., is bottomed out in the support cage, and is subject to low compressive loading when the end cap is compressed by the external clamping arrangement.

Tensile and compressive forces generated during insertion, removal, and filtration may cause wear on a filter element which in turn may cause a defect in the filter element, e.g., a path for fluid by-pass. In order to reduce tensile loading on the filter element, a filter assembly embodying one aspect of the invention is preferably designed such that during operation, the filter element is subject to a slight compressive loading by the external clamping arrangement, and during insertion and removal the filter element is subject to substantially little or no tensile loading. The slight compressive loading during operation is such that minimal or no wear on the filter element is caused.

Figures 13a and 13b are sectional views of this exemplary embodiment of the filter assembly of the present invention. As described above, the filter assembly 500 comprises a filter element 502 removably mounted in a perforated support cage 504. The filter element 502 includes a filter pack 506 comprising at least one layer of a filter medium, a first end cap 508, and a second end cap 510. The filter element 502 also comprises a handle 512 which facilitates the insertion and removal of the filter element 502 into or out of the perforated support cage 504.

The filter assembly 500 may be disposed in an opening in a tubesheet 600 of a filtration system and supported therein by the perforated support cage 504. As in the above described embodiments, the tubesheet 600 generally comprises a plurality of openings to accommodate a plurality of filter assemblies. In addition, the tubesheet 600 may be configured such that the filter assembly 500 may be vertically or horizontally oriented within the filtration system, or the filter assembly 500 may be oriented at any angle between vertical and horizontal. In the exemplary embodiment, the tubesheet 600 is configured such that the filter assembly 500 is vertically oriented.

The perforated support cage 504 axially supports the filter element 502 in the opening of the tubesheet 600. In addition, the perforated support cage 504 radially supports the filter element against outwardly directed forces during filtration assuming inside to outside flow and also helps to give the filter element 502 axial strength and rigidity against bending. If, however, the fluid flow is outside to inside, a core may be utilized in addition to or instead of the perforated support cage 504 as described in the above described embodiments. In the exemplary embodiment, only a perforated support cage 504 is utilized.

The perforated support cage 504 may comprise a substantially cylindrical configuration having first and second ends, preferably a first open end and a second end which is at least partially closed. The perforated support cage 504 preferably includes an upper portion that is permanently or removably mounted to the tubesheet 600 and a lower portion which surrounds the filter pack 506. The upper portion comprises a cylindrical sealing surface for the first end cap 508 which is described in detail subsequently. The upper portion is mounted to the tubesheet 600 in a manner that prevents fluid by-pass and preferably comprises no perforations or openings through which fluid may pass. The lower portion comprises openings to permit the passage of fluid through the filter element 502 without creating any substantial pressure differential across the support cage 504. The openings, however, are preferably small enough to prevent the filter medium from expanding into the openings and becoming trapped and/or damaged in the openings if the filter pack 506 expands from the pressure during filtration. The shape and size of the lower portion and the openings may be identical to the previously described embodiments.

The first end of the support cage 504, as described above, may be an open end through which the filter element 502 may be inserted and removed. The first end is defined by the upper portion and may comprise an initial tapered section to facilitate insertion of the filter elements 502. In a preferred embodiment the upper portion comprises substantially straight cylindrical walls. The second end is at least partially closed to support the filter element 502. The second end may comprise a flat annular flange which extends radially inward and upon which the filter element 502 may rest, or preferably, the second end comprises a flat circular or arched base 514 which completely encloses the second end.

In an alternative embodiment the support cage comprises only the lower portion, and the lower portion is attached to one face, e.g., the lower face, of the tubesheet surrounding the opening in the tubesheet. The opening in the tubesheet defines a cylindrical wall which, in turn, defines a cylindrical sealing surface for the first end cap. The filter pack 506 may comprise any suitable configuration and medium or combination or media, which are typically selected based upon the particular application for which the filter pack 506 is to be utilized. For example, the filter medium may have a uniform or graded pore structure, may be non-pleated or pleated, and if pleated, the pleats may extend radially or they may be in a laid-over configuration. In a preferred embodiment, the filter pack 506 comprises the same or similar configuration and media as the filter pack illustrated in Figure 7, including a wrap 518.

The second end cap 510 of the filter element 502 may be an open end cap or a blind end cap. An open end cap may be particularly advantageous for connecting filter elements 502 end to end to construct longer filter elements as mentioned above and described in detail subsequently. In a preferred embodiment, the second end cap 510 may be a blind end cap. The second end cap 510 may comprise any suitable configuration and materials for the particular application that the filter element 502 is to be utilized. For example, the second end cap 510 may be identical to any of the blind end caps described above. In a preferred embodiment, the second end cap 510 comprises a substantially circular configuration, e.g., a circular disc, with an outside diameter substantially equal to the outside diameter of the filter pack 506. In addition, the second end cap 510 may also comprise a structure

which protrudes inwardly towards the center region of the filter element 502 to reduce dead zones in the fluid flow path. The structure may be identical to the structure 38 illustrated in Figures 3a and 3b.

In accordance with an aspect of the present invention, the first end cap 508 comprises a suitable arrangement for facilitating substantially reduced resistance, even resistance free, insertion and removal of the filter element 502 to and from the perforated support cage 504 and maintaining a fluid tight seal between itself and the perforated support cage 504 or the tubesheet 600 during operation. In the exemplary embodiment, the first end cap 508 comprises a multiple element structure including first and second end cap segments 522,524 and a sealing member 526 positioned between the first and second end cap segments 522,524. The first and second end cap segments 522,524 may be connected by first and second engagement members 528,530.

The first segment 522 may comprise an annular disc having upper and lower parallel surfaces and an outer diameter greater than or substantially equal to the diameter of the filter pack 506. A central opening defined by the annular disc provides a fluid flow path such that fluid may flow into or out of the filter element 502. The first engagement member 528 preferably comprises a cylindrically arranged flange-like member 532 extending perpendicularly from the lower surface of the annular disc. In the exemplary embodiment, the outer diameter of the flange-like member 532 is smaller than the outer diameter of the annular disc, defining a sealing section 534 between the outer edge of the annular disc and the flange-like member 532. The first engagement member 528 also comprises an engagement lip 536 positioned at the free end of the flange-like member 532. The engagement lip 536 includes a bevelled section 538 and a contact section 540. The bevelled section 538 allows the first segment 522 to be joined with the second segment 524 and the contact section 540 prevents separation of the two segments 522,524 once joined. The first segment 522 may also comprise the handle 512 for insertion and removal of the filter element 502 to/from the perforated support cage 504. The first segment 522 may comprise plural elements, e.g., separate disc and flange-like member, or may be formed as a one-piece structure.

The second segment 524 may also comprise an annular disc having upper and

lower parallel surfaces, an outer diameter greater than or substantially equal to the diameter of the filter pack 506 and a central opening for fluid flow. The second engagement member 530 also preferably comprises a cylindrically arranged flange-like member 542 extending perpendicularly from the upper surface of the annular disc. The second engagement member 530 also comprises an engagement lip 544 positioned at the free end of the flange-like member 542. The engagement lip 544 includes a contact section 546 and a sealing section 548. The lower parallel surface of the second segment 524 may be attached to the end of the filter pack 506 by any suitable means, for example, by any of the means described above with respect to the previous embodiments. The second segment 524 may comprise plural elements or may be formed as a one-piece structure.

The first and second segments 522,524 may comprise any suitable fluid impervious material which is compatible with the particular process fluid being filtered and which will provide a fluid tight seal with the filter pack 506. For example, the first and second segments 522,524 may comprise any impervious metals, ceramics, elastomers, or polymeric materials. In an exemplary embodiment, the first and second segments 522,524 comprise a moldable polymeric material such as polypropylene and nylon.

The first and second segments 522,524 may be connected together by interlocking the first and second flange-like members 532,542 in slidable engagement, wherein the first end cap 508 comprises an extendable end cap. In the exemplary embodiment, the first flange-like member 532 and the second flange-like member 542 are arranged such that the engagement lips 536,544 make contact with one another to prevent the first and second segments 522,524 from separating. However, the length of the first and second flange-like members 532,542 are such that there may be movement in the axial direction between the first and second segments 522,524. Essentially, the first segment 522 may be moved from a first position wherein the contact section 540 of the engagement lip 536 is in contact with the contact section 546 of the engagement lip 544 (Figure 13b) to a second position wherein the contact section 540 is spaced from and no longer in contact with the contact section 546 (Figure 13a). Accordingly, a first gap 550 of varying height and defining a substantially annular region may be formed between the sealing section

534 of the first segment 522 and the sealing section 548 of the second segment 524, and a second gap 552 of varying height may be formed between the contact section 540 of the engagement lip 536 of the first segment 522 and the contact section 546 of the engagement lip 544 of the second segment 524. The sealing member 526 may be positioned in the first gap 550, and the length of the first and second flange-like members 532,542 may be any suitable length and is preferably sized to accommodate the particular sealing member 526.

The sealing member 526 may comprise any suitable structure that is deformable under compressive loading. For example, the sealing member 526 may comprise an O-ring seal and preferably comprises an X-ring seal. The sealing member 526 has an outside diameter substantially equal to or less than the outside diameter of the first and second segments 522,524 under a no load condition, i.e., when the first and second segments 522,524 are further spaced from each other and the sealing sections 534, 548 are spaced a distance greater than the thickness of the sealing member 526. When the first and second segments 522,524 are pressed together, the sealing sections 534, 548, in turn, sealingly engage and compress the sealing member 526. The sealing member 526, in turn, expands to a diameter greater than the outside diameter of the first and second segments 522,524, contacting and sealing against the sealing surface of the perforated support cage 504 or tubesheet 600. Essentially, when subjected to compressive loading, the sealing member 526 sealingly engages the sealing sections 534, 548 and deforms in such a manner as to sealingly engage the sealing surface of the perforated support cage 504. Under compressive loading, the first segment 522 is forced towards the second segment 524, thereby decreasing the first gap 550 in which the sealing member 526 is positioned, causing it to deform while the second gap 552 increases. As in the previously described embodiments, when the sealing member 526 is compressed, it has the largest outside diameter of the filter element 502. In particular, the sealing member 526, when compressed, has an outside diameter greater than the largest outside diameter of the filter pack. The sealing member 526 may comprise any suitable material, such as an elastomeric material, which is impervious to fluid flow and which is elastically deformable under compressive loading. In an exemplary embodiment, the sealing member 526 comprises silicone and nitro rubbers.

Under a no load condition, for example, when the filter element 502 is first inserted into the perforated support cage 504, the sealing member 526 is relaxed and therefore does not extend significantly past the first and second segments 522,524. Accordingly, there is substantially little or no resistance to the movement of the filter element 502 into the perforated support cage 504. In particular, there is substantially little or no resistance to the movement of the first end cap 508 into the upper portion of the perforated cage 504 or the tubesheet 600. Similarly, when the filter element 502 is removed from the perforated support cage 504 by pulling on the handle 512, the first and second segments 522,524 separate, the sealing member 256 relaxes and assumes its non-deformed shape. Accordingly, there is substantially little or no resistance to the movement of the first end cap 508 out of the upper portion of the perforated support cage 504 or the tubesheet 600.

However, when the filter element 502 is to be utilized, the filter element 502 is subjected to a compressive loading and the sealing member 526 is energized between the first segment 522 of the end cap 508, the second segment 524 of the end cap 508, and the upper portion of the perforated cage 504 or the tubesheet 600. The filter element 502 may be subjected to compressive loading by any suitable arrangement for clamping the filter element 502 in position in the perforated support cage 504, e.g., by a housing cover or a clamping plate of the filtration system (not illustrated). The clamping plate may be variously configured. For example, the clamping plate may comprise a flat plate having openings corresponding to the openings in the tubesheet 600 or it may comprise a grid having a multiplicity of smaller openings. When the filter elements 502 are positioned in the perforated support cages 504, the clamping plate is pressed against the first end caps 508, e.g., by connecting the clamping plate to the tubesheet 600 or by simply closing the housing cover. The filter elements 502 may thereby be bottomed against the support cages 504 and the first and second segments 522,524 of each first end cap 508 are pressed together, expanding and energizing the sealing member 526. The first and second sealing sections 534, 548 sealingly engage the sealing member 526, preventing by-pass of fluid from the interior of the first end cap 508 to the exterior of the filter pack 506 between the first and second segments 522,524. Further, the deformed sealing member 526 sealingly engages the upper portion of the perforated support

cage 504, preventing by-pass of fluid from one side of the tubesheet 600 to the other side between the end cap 508 and the upper portion of the support cage 504 or the tubesheet 600.

In the filtration process, assuming inside to outside fluid flow, the process fluid flows through the opening in the first end cap 508 into a central region of the tubular filter element 502 at a predetermined flow rate and pressure. The process fluid in this central region passes through the filter pack 506, including the filter medium, whereby contaminants in the process fluid are removed. While the flow rate remains substantially constant, there is typically a pressure differential between the process fluid on the upstream side of the filter pack 506 and the process fluid on the downstream side of the filter pack 506. This pressure differential results in forces acting upon the filter element 502 in both the radial and axial directions. The perforated support cage 504 and the wrap 518 provide support for the filter pack 506 against the radially directed forces. Since the filter element 502 is already bottomed out in the perforated support cage 504, the filter element 502 is supported against the forces acting in the axial direction.

When the filter element 502 is to be removed, the clamping arrangement is released, thereby substantially removing the compressive loading on the sealing member 526. The filter element 502 may then be gripped by the handle 512, either by a human operator or a robotic manipulator, which causes the first and second segments 522,524 to further separate, thereby removing compressive loading on the sealing member 526, which in turn allows the sealing member 526 to relax and return to its natural position. Lifting the filter element 502 by the handle 512 pulls the first segment 522 from the second segment 524 thereby increasing the first gap 550 and reducing the second gap 552. The first and second engagement lips 536,544 prevent the two segments 522,524 from coming apart when subjected to tensile loading during removal and transmit the lifting forces to the remainder of the filter element 502.

In accordance with one aspect, the present invention is directed to a separation element. For example, the present invention is directed to a separation element, such as a long, large inside diameter separation element, which effectively handles a large flow of process fluid in a small housing with a small pressure drop.

A filter element such as those illustrated in Figures 1, 2, 11, 12 and 13 preferably have a length greater than forty inches and an interior diameter of at least two inches, and more preferably have a length equal to or greater than sixty inches and an interior diameter of at least three inches and more preferably about four or more inches. Filter elements such as these offer the advantage of increased filter medium surface area available for filtration. Other advantages may also be recognized, including a reduction in expenses for materials and labor, and a reduction in waste. As is explained in detail subsequently, fewer longer and greater diameter filter elements are required to achieve equivalent throughput than many more shorter and smaller diameter filter elements. Accordingly, fewer filter elements have to be purchased and less labor is involved in changing the filter elements. In addition, less waste is generated in terms of discarded filter elements and the packing in which they are delivered. The longer filter elements may also be crushable to reduce the actual volume of the waste.

The folding of a sheet of filter medium into corrugated form has always posed unusual difficulties. Many conventional corrugating machines require that corrugations be imposed across the shorter dimension of the filter medium or the filter composite, i.e., widthwise or transversely of the long dimension of the composite. Consequently, the length of pleated filter packs is limited by the maximum width of filter composite, which is generally less than forty inches. Longer pleated filter elements may be constructed, for example, by joining open end caps, e.g., joiner caps, to both ends of several filter packs to form several short filter elements. A string of short filter elements are then connected end-to-end to form a long filter element by joining the open joiner cap of one short filter element to the open joiner cap of an adjacent short filter element. The last short filter element of the string is generally blinded by a blind end cap. Increasing the length without increasing the diameter of the filter element, however, may result in an undesirably high filter support core pressure differential. The core pressure differential is the pressure drop due to the length of the filter flow path axially through the interior of the filter element and is a function of various parameters including the length and diameter of the fluid flow path.

In accordance with another aspect of the invention, both the length and the diameter, especially the inner diameter of the filter element may be increased. The longer, larger diameter filter elements are preferably constructed by joining together two or more shorter filter pack sections using open end cap unions or joiner caps to achieve hollow filter arrangements with lengths of preferably greater than forty inches and interior diameters of at least two inches, more preferably greater than sixty inches and interior diameters of at least three inches and more preferably about four or more inches. Essentially, as the length of the filter elements is increased, the inside diameter is also preferably increased to reduce the core pressure differential. Depending on the length of the particular filter element and the lengths of the shorter filter pack sections, one or more pairs of joiner caps may be utilized. The two end caps utilized in these longer, larger diameter filter elements may comprise any suitable configuration such as those described above. However, one of the end caps joined to the filter pack preferably comprises a slidable end cap such as the slidable end cap 220 illustrated in Figure 12. The slidable end cap 220 allows for axial movement of the filter element 212 while providing a fluid tight seal via a seal 228 having an outside diameter greater than the largest outside diameter of the hollow filter element 212. The filter pack may comprise any suitable medium such as described above. Preferably, the filter pack comprises a material and configuration which is capable of supporting its own weight, wet or dry, without an interior or exterior support structure even at lengths greater than forty inches. In a preferred embodiment, the filter pack comprises a glass fiber medium having a pleated structure. The pleats may extend radially or they may be in a laid-over configuration as described in detail above.

The joiner caps may comprise any suitable configuration and may be attached to the shorter filter pack sections by any suitable means. Further, adjacent joiner caps may be joined to one another in any suitable manner which ensures that the filter pack sections are connected substantially coaxially. In the exemplary embodiment, the joiner caps may be polycapped to the ends of the shorter filter packs which are to be joined together and then the adjacent joiner caps are joined by heat welding. The joiner caps may comprise a substantially annular configuration. The side or surface which is to be attached to the end of a filter pack

section may be melted by any suitable means to create a subannulus of molten material. The filter pack section is then plunged into the molten material which is then allowed to cool and solidify thereby joining the joiner cap to the end of the filter pack. Once the joiner caps are attached to the ends of the filter pack sections, the joiner caps may be secured to one another to form larger sections. The joiner caps may also comprise at least a first sacrificial welding ridge positioned near its outer periphery on the joining side or surface, i.e., the surface which contacts the other joiner cap. The sacrificial welding ridge on each joiner cap may be melted by a heat source such as a radiant heater positioned in proximity to the joiner caps. Once the sacrificial welding ridge on each joiner cap is molten, the shorter filter pack sections may be plunged together thereby bringing the joiner cap into contact. Once cooled, the shorter filter pack sections are securely connected to one another. For added strength and stability, the joiner caps may comprise a second sacrifical welding ridge along its inner periphery. The second sacrificial welding ridge may protrude from each joiner cap a distance less than the first sacrificial welding ridge and are preferably not completely melted during the joining process. Accordingly, the second sacrificial welding ridge provides support along the inner periphery and maintains the two filter packs in coaxial relationship. For the reasons discussed above with respect to the core pressure differential, the inside diameter of the joiner caps may be approximately equal to the inside diameter of the pack.

The filter pack sections utilized to construct the longer, larger diameter filter elements may be of any size. For example, each filter pack section may be of equal length or alternatively, each filter pack section may have variable or unequal lengths.

Alternatively, if the corrugating apparatus were able to pleat in the longitudinal direction, longer filter elements may be constructed without joiner caps. U.S. Patent No. 4,252,591 to Rosenberg and assigned to the same assignee as the present invention discloses a corrugating apparatus and process for forming corrugations extending longitudinally to the filter composite. U.S. Patent No. 4,252,591 is incorporated by reference herein. Because the corrugations are formed longitudinally to the filter composite, variable length, e.g., filter packs of any suitable length, may be formed.

However, while the length of the corrugated filter pack is virtually unlimited,

the diameter of the filter pack is limited by the maximum width of the filter composite. Increasing the length without increasing the diameter of the filter element may, as stated above, result in an undesirably high filter support core pressure differential. The core pressure differential, as stated above, is the pressure drop due to the length of the filter flow path axially through the interior of the filter element and is a function of various parameters including the length and diameter of the fluid flow path, e.g., the length and throat dimension of the interior of the filter element. Thus, a filter element formed in accordance with U.S. Patent No. 4,252,591 may have any arbitrary length but it may not function effectively because the diameter is limited and the core pressure differential is unacceptably high.

In accordance with another aspect of the invention, both the length and the diameter, especially the inner diameter, of the filter element may be increased. In particular, the filter element may be formed by longitudinally pleating the filter medium or the filter composite to provide a corrugated filter pack section of any suitable length. For example, in preferred embodiments, the length of the corrugated filter section is greater than about forty inches, preferably greater than about fifty inches, and more preferably greater than or equal to about sixty inches.

To form a filter element embodying this aspect of the invention, any suitable filter medium or a filter composite including a filter medium may be fed into a longitudinal pleating apparatus, such as that disclosed in U.S. Patent No. 4,252,591. The apparatus of U.S. Patent No. 4,252,591 comprises a fan-shaped fold-former to form the corrugations in the filter composite. The fan-shaped fold-former includes a plurality of corrugation folds having alternating peaks and depressed portions. A pair of driven cylindrical rolls draw the filter composite through the fold-former. In addition, flexible chains, because of their weight, facilitate in corrugating the filter composite by conforming the filter composite to the undulating contour of the fold-former surface. In an alternative embodiment, the fan-shaped fold-former and chains may be replaced with upper and lower vaned guides which form corrugations into the filter composite. The vanes may be alternately disposed in the upper and lower guides and may increase in height along the length of the guides. In addition, the apparatus may include means for heating the filter composite in order to facilitate the forming of the corrugations. Heat may make the filter composite more

pliable. A gripping mechanism which grabs the ends of the corrugated filter composite may be utilized to pull the material through the vaned guides rather than rollers.

Once a plurality of the corrugated filter pack sections are formed, they are then joined by means of a plurality of longitudinal side seal arrangements to provide a filter pack having not only any suitable length but also any suitable diameter. For example, in preferred embodiments, a filter pack having a length greater than forty inches, preferably greater than fifty inches, and more preferably greater than or equal to sixty inches, also has a plurality of longitudinal side seal arrangements yielding an inner diameter greater than about three inches, more preferably greater than about four inches, and even more preferably at least about five inches.

Longitudinal side seal arrangements are preferably utilized to join the edge flaps of each pair of adjacent corrugated filter pack sections together to form a single, extra wide corrugated filter pack section. The two remaining edge flap sections of the single, extra wide corrugated filter pack section are then joined together utilizing a longitudinal side seal arrangement to form a filter pack having an inner diameter greater than two inches, more preferably greater than three inches, more preferably greater than about four inches, and even more preferably at least about five inches. The edge flaps may be abutted in a variety of configurations for forming the side seal arrangements. The longitudinal side seal arrangements preferably extend in the axial direction over substantially the entire length of the corrugated filter sections, i.e., in the direction of the corrugations, and form a fluid impervious seal between the corrugated filter sections. Each side seal arrangement may include one or more side seals comprising, for example, a thermoplastic or pressure sensitive bonding agent, and which is positioned between the abutting edge flaps.

The side seal arrangements may be formed in any suitable manner which seals the longitudinal edges of the corrugated filter sections to one another. For example, U.S. Patent No. 5,360,650, which is assigned to the same assignee as the present invention and is incorporated by reference, discloses several exemplary methods for forming the side seal arrangements. Further, any number of side seal arrangements may be utilized to provide a predetermined filter element diameter.

For example, in Figure 14 an exemplary filter pack 16 helically wound with a wrap 18 comprises four longitudinal side seal arrangements 250 joining four corrugated filter pack sections 252, 254, 256, 258 to one another.

FILTER ELEMENT	A	B	C	D
Number of Side seals	1	2	3	4
Pack Inner Diameter (in)	1.3	2.6	3.9	5.2
Pack Outer Diameter (in)	2.4	3.7	5.0	6.3
Area per 60" element (ft^2)	16.3	32.6	48.9	65.2
Housing I.D. (in)	2.73	4.52	6.34	8.17
Flow rate (gpm) @ 1 psid pack + core losses	25 gpm	110 gpm	240 gpm	415 gpm
Flow rate per ft^2 @ 1-lb. drop	1.53 gpm/ft^2	3.37 gpm/ft^2	4.91 gpm/ft^2	6.36 gpm/ft^2

TABLE 1

Longer, larger inside diameter filter elements offer the advantage of increased filter medium surface area available for filtration, as well as a reduction in waste and expenses for materials and labor because of a decreased change-out frequency. These, as well as other advantages may be recognized regardless of whether they have joiner caps or multiple side seals. In the preferred embodiment, the filter elements are constructed by joining together two or more shorter filter pack sections as described above rather than through longitudinal pleating and side seals; however, the results in Table 1, shown above, are substantially the same for the filter elements in accordance with the preferred embodiment. Table 1 lists several characteristics of four different sixty inch long filter elements A-D, each having a different number of longitudinal side seals and a different pack inner diameter, and the housings associated with these filter elements. Each of the filter elements A-D comprises no more than two end caps and a laid-over pleated filter pack comprising upstream and downstream drainage meshes which sandwich a meltblown fibrous depth filter medium having a ten micron removal rating. The

drainage and filter media are similar to the media of a filter element available from Pall Corporation under the trade designation Ultipleat™ Profile. The number of side seals and the inner diameter of the filter elements vary from one side seal and 1.3 inch for filter element A to four side seals and about five inches for filter element D. Beginning with filter element B but even especially for filter elements C and D, the flow rate per square foot of filter medium is particularly high. For example, filter element C, which has an inner diameter of about four inches, has a total filter medium area of about forty-nine square feet and a flow rate per square foot of about 4.9 gallons per minute. This results in a particularly high throughput, i.e., 240 gpm, through a relatively small housing, i.e., a housing having an inner diameter of about 6.3 inches. The characteristics of filter element D, which has an inner diameter of about five inches, are even more advantageous, yielding a throughput of about 415 gpm through a housing, having an inner diameter of only about 8.2 inches. Preferably, filter elements of forty inches in length have inside diameters of at least two inches and filter elements of sixty inches preferably have inside diameters of at least three inches.

The advantages offered by longer, larger diameter filter elements may be most clearly recognized in filter systems utilizing multiple filter elements. Specifically, in multiple filter element systems, many smaller diameter, shorter length filter elements may be replaced by fewer larger diameter, longer length filter elements, achieving the same flow rates in much smaller diameter housings. Table 2, given below, summarizes a comparison between filters containing sixty inch long, six inch diameter filter elements and filters containing forty inch long, two and a half inch filter elements. As can be seen from the Table 2, the number of filter elements and the housing size may be significantly reduced by using the longer, larger diameter filter elements. Accordingly, smaller diameter housings may be utilized resulting in significant cost savings for the housings and a reduction in labor time to change out the filter elements.

Each component, feature, or subset of components or features of the previously described embodiments may be combined with one or more of the components, features, or subsets of components or features of the above described longer, larger inside diameter filter element embodiments or vice versa without

departing from the scope of the invention.

Flow rate* (GPM)	6"x60" Filter Elements		2.5"x40" Filter Elements	
	Qty. of Elements	Housing I.D. (inches)	Qty. of Elements	Housing I.D. (inches)
900	1	8.2	20	18.9
4,500	5	24.5	102	38.1
6,300	7	24.5	143	45.6
13,500	15	40.8	307	65.6

*Flow rates reflect a 3 psid clean ΔP contribution of pack and core losses.

TABLE 2

In accordance with one aspect, the present invention is directed to a separation assembly. For example, the present invention is directed to a separation assembly which allows a removable separation element to be supported by a reusable cage.

A wide variety of filtration system housings may accommodate any of the above-described filter elements, especially the longer, larger diameter filter elements. For example, Figures 15 and 16 illustrate two different exemplary filtration system housings which contain the longer, larger diameter filter elements. Because the filter elements are longer and have a larger diameter and thus offer additional surface area available for filtration, the housing 300, 400 may comprise a smaller diameter because less filter elements are required. Both of the illustrated housings 300, 400 may be oriented vertically or horizontally or at any angle between vertical and horizontal. Typically, the housings of filter systems will vary depending on the particular application. In particular, the mounting of the support cages and the filter elements within the housing may vary significantly. One factor which determines the particular manner in which the cage and element are mounted is the orientation of the housing. For example, in a vertically oriented housing, the perforated support cages may simply be positioned in the openings, whereas in a horizontally oriented housing, the perforated support cages may be welded to the tubesheets or otherwise

permanently attached to the tubesheets.

The filtration system may also include a support plate which may be utilized to hold and position the filter elements. The support plate may be utilized to provide support for the filter elements at the ends opposite the tubesheet. As illustrated in Figure 15, the process fluid enters through an inlet 302, flows through openings in the tubesheet 304, and into the hollow filter elements 306 which may be designed in accordance with any of the above described embodiments. The filtrate flows through the filter pack of each filter element 306, through the perforated support cages 308, and out of the housing 300 through an outlet 310. The outlet 310 is generally positioned between the tubesheet 304 and the support plate 312 to reduce any possible pressure build-up which may occur if the fluid flow is directed through openings in the support plate 312 to an outlet. In Figure 16, the process fluid enters through an inlet 402 and flows through a central opening or conduit 404 in the support plate 406, through openings in the tubesheet 408 and then into the hollow filter elements 410. The filtrate flows through the filter pack of each element 410, through the perforated support cages 412, and out of the housing 400 through an outlet 414.

As illustrated in Table 2 above, the advantages offered by longer, larger diameter filter elements may be most clearly recognized in filter systems utilizing multiple filter elements. Accordingly, a tubesheet designed to accommodate a plurality of larger filter elements may be constructed to provide sufficient structural support. However, in order to achieve higher filtration efficiencies, the spacing between the filter elements, i.e., the pitch, is preferably minimized, thereby reducing the spacing between the filter element openings in the tubesheet; therefore, reducing the potential support capabilities of the tubesheet. For example, for filter packs having about a six inch outside diameter and a pitch of about six and three quarters of an inch on center, the space between the openings in the tubesheet may be approximately one half inch taking into account that the end caps may have a slightly greater outside diameter than the filter packs. In order to compensate for the potential increase in filter element weight due to the increased size of the element, i.e., greater than forty inches in length and inside diameters of at least three inches, additional support may be required. One way in which to increase the

support capabilities of the tubesheet is to increase the thickness of the tubesheet. Since, as explained above, the filter elements are preferably designed to move axially within the support cage, the tubesheet preferably has a thickness to accommodate the full axial travel distance of the filter element. Depending on the material utilized to construct the tubesheet, the thickness of the tubesheet may be increased to provide additional structural support.

Alternatively, in order to support the structural loading on the tubesheet, a secondary support structure may be utilized. For example, as illustrated in Figure 15, the support plate 312 may be utilized in conjunction with a structure to transmit the forces acting on the tubesheet 304 to the support plate 312, whereby the tubesheet 304, the support plate 312 and the force transmission structure function as a framework supporting the filter elements 306. Any suitable structure may be utilized to transmit the forces from the tubesheet 304 to the support plate 312. For example, one or more tie rods connected between the tubesheet 304 and the support plate 312 may be utilized to transmit the forces, thereby providing additional support to the tubesheet 304. Alternatively, one or more of the perforated support cages 308 in which the filter elements 306 are positioned may be utilized as the force transmission structure. For example, one or more of the support cages 308 may contact or be attached to the support plate 312 and transmit forces from the tubesheet 304 to the support plate 312. In yet another alternative embodiment, the base of the housing 300 itself may serve the function of the support plate and any suitable structure, such as tie rods or support cages 308, may extend between the tubesheet 304 and the base of the housing 300 to transmit the forces from the tubesheet 304 to the base of the housing 300.

The tubesheet 304 may be removably mounted within the housing 300 or permanently mounted in the housing 300 by welding or any other suitable means. The support plate 312, if one is utilized, may also be removably or permanently mounted in the housing 300. Typically, the tubesheet and the support plate are in proximity to the respective ends of the filter elements, thereby providing the maximum support. The outlet of the filter system is preferably positioned between the tubesheet and the support plate on the housing to minimize or avoid a pressure differential that may arise due to passage of the fluid through openings in the

support plate.

In filtration systems utilizing bag filters, the filter housing would be oriented vertically. However, the exemplary filters of the present invention may be utilized in place of many of these bag filters; accordingly, filtration systems which were constrained to utilized vertically oriented housings may now utilize horizontally oriented housings because the support cages can provide cantilevered support for the filter elements. The new orientation may afford greater flexibility in positioning the filtration system.

Although shown and described is what is believed to be the most practical and preferred embodiments, it is apparent that departures from specific methods and designs described and shown will suggest themselves to those skilled in the art and may be used without departing from the spirit and scope of the invention. The present invention is not restricted to the particular constructions described and illustrated, but should be construed to cohere with all modifications that may fall within the scope of the appended claims.